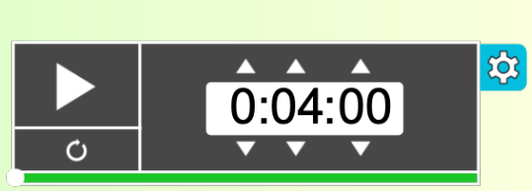
Particle physics	**The alpha scattering expreriment**

Learning objectives	**MUST (C)**	Define the nuclear model of the atom and its constituents
	SHOULD (B)	Describe the alpha-scattering experiment and its findings
	COULD (A/ A*)	Find the distance of closest approach of an alpha particle

STARTER: Think back to GCSE physics, when we examined the alpha-scattering experiment. Which of the following did this experiment identify? Which pre-dated the experiment, and which followed?

The existence of neutrons
The existence of the nucleus
The existence of electrons

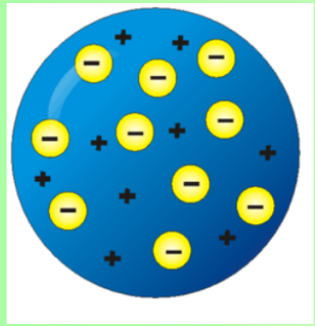


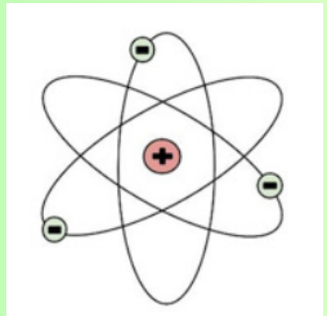
EXTENSION: What was the model of the atom that was not consistent with the alpha-scattering experiment?

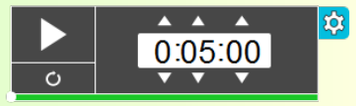
Particle physics	**Alpha scattering**

MUST (C)	Define the nuclear model of the atom and its constituents

The alpha-scattering experiments were performed between 1908 and 1913. Prior to this, the scientific model of the atom was the 'plum pudding' model, which drew upon the knowledge that electrons existed and also that the overall charge was neutral. The model proposed by Rutherford following the experiment had a very small nucleus with electrons orbiting around it randomly. (Electron shells were proposed later, by Bohr).

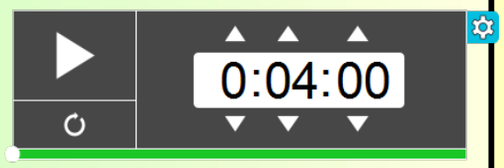






rest mass of electron (m_e)	9.1093897(54)E-31 kg
	5.48579903(13)E-04 amu
rest mass of proton (m_p)	1.6726231(10)E-27 kg
	1.007276470(12) amu
	1836.152701(37) m_e
rest mass of neutron (m_n)	1.6749286(10)E-27 kg
	1.008664904(14) amu

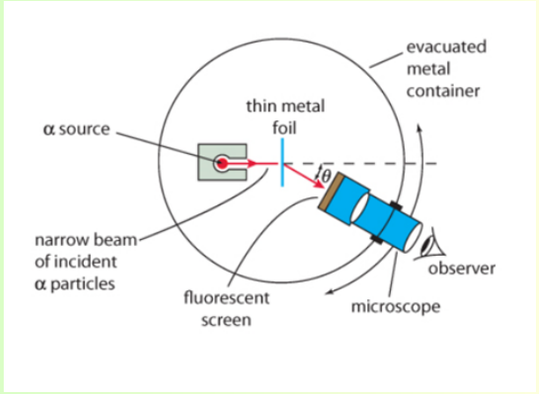
The amu, or atomic mass unit, is 1/12th of the mass of a neutral C-12 atom. Neutrons are very slightly larger than protons, and electrons are much smaller than both.



Particle physics	**The alpha-scattering experiment**

SHOULD (B)	Describe the alpha-scattering experiment and its findings

The narrow beam of alpha particles, with the same kinetic energy, were fired towards the gold foil. When the scattered particles from the gold foil hit the screen in front of the microscope, they caused it to fluoresce. The microscope could be moved around to see the amount of scattered particles at different angles.



What conclusions could be drawn from the following observations?

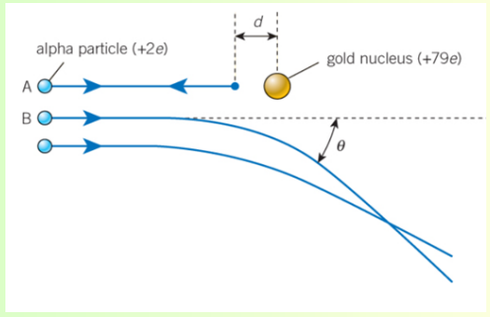
Only 1 in 2000 alpha particles were scattered

1 in 10,000 were scattered by more than 90°

The experiment showed that the vast majority of the atom was empty space, with a tiny centre where nearly all of the mass was concentrated.

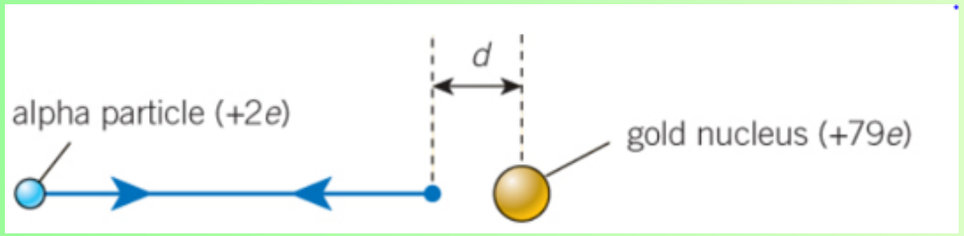
Subsequent calculations showed that the radius of a nucleus is approximately 10^{-15} m, while the radius of an atom is about 10^{-10} m.

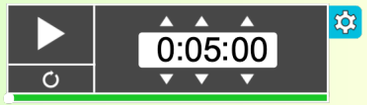
Why do the two scattered electrons have different angles of deviation?



Particle physics	**The alpha-scattering experiment**
COULD (8/9)	Find the distance of closest approach of an alpha particle

An alpha particle is heading towards a gold nucleus. At some point, it will stop before it turns back. At what point will it stop?





Which energy transfer is taking place?

Kinetic energy of alpha particle to electric potential energy of alpha particle

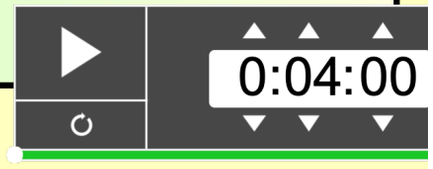
The initial kinetic energy of Rutherford's particles was 1.2×10^{-12} J.

Use EPE eqn ($qQ/4\pi\varepsilon_0 d$) to find the distance of closest approach. Extension: what would the closest approach be for a particle with double the speed?

$$1.2 \times 10^{-12} = \frac{Qq}{4\pi\varepsilon_0 d} \qquad (Q = Ze = 79e \text{ and } q = 2e)$$

$$1.2 \times 10^{-12} = \frac{79 \times 2 \times (1.60 \times 10^{-19})^2}{4\pi \times 8.85 \times 10^{-12} \times d}$$

$$d = 3.0 \times 10^{-14} \approx 10^{-14}\,\text{m}$$



Particle physics	**The alpha-scattering experiment**
COULD (8/9)	Find the distance of closest approach of an alpha particle

5 Alpha particles of kinetic energy 8.8 MeV are fired at lead atoms. The charge on the nucleus of lead is $82e$. Calculate:

a the minimum distance the alpha particles approach to the nucleus of lead *(4 marks)*

b the maximum electrostatic force experienced by the alpha particle. *(3 marks)*

6 A tiny droplet of oil diameter 1.0 mm is placed on water. The oil spreads out as a circular disc of thickness approximately one atom thick. Estimate the radius of this oil disc. *(3 marks)*

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5 a $8.8\times10^{6}\times1.6\times10^{-19}=\dfrac{Qq}{4\pi\varepsilon_0 d}$ $(Q=Ze=82e$ and $q=2e)$ [2]

$1.408\times10^{-12}=\dfrac{82\times2\times\left(1.6\times10^{-19}\right)^2}{4\pi\times8.85\times10^{-12}\times d}$ [1]

$d=2.68\times10^{-14}\,\text{m}\approx2.7\times10^{-14}\,\text{m}$ [1]

b $F=\dfrac{Qq}{4\pi\varepsilon_0 r^2}=\dfrac{82\times2\times\left(1.6\times10^{-19}\right)^2}{4\pi\times8.85\times10^{-12}\times\left(2.68\times10^{-14}\right)^2}$ [2]

$F=53\,\text{N}$ [1]

6 initial volume = final volume [1]

$\dfrac{4}{3}\pi\times\left(0.5\times10^{-3}\right)^3=10^{-10}\times\left(\pi\times r^2\right)$ [1]

$r=1.29\,\text{m}\approx1.3\,\text{m}$ [1]

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PLENARY: Why was gold used in the experiment? What would have happened if a material with a greater atomic number had been used?

EXTENSION: What would have happened if neutrons had been used?